AERODYNAMIC ATHLETIC APPAREL

BACKGROUND FOR U.S. PATENT APPLICATION

AND / OR TRADEMARK PROTECTION

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AERODYNAMIC ATHLETIC APPAREL

Field of the Invention

This invention relates to the field of aerodynamics, athletics, personal apparel and transportation, and associated technologies which permit the saving of energy, or more efficient use of energy, thus enabling the attainment and maintenance of personal movement or transport at higher velocities.

Background of the Invention

In the course of the last twenty years increased attention has focused upon the energy cost of aerodynamic drag on human performance. These efforts have largely focused on the sports of bobsled, skiing, speed skating and bicycling where aerodynamic drag has an easily recognized and sometimes dramatic effect on observed performance: e.g., Aerodynamic drag can account for approximately 90% of the total energy expenditure incurred in high speed bicycling. (Chester R. Kyle, Ergonomics, 1979, Vol. 22, No. 4, "Reduction of Wind Resistance and Power Output of Racing Cyclists and Runners Travelling in Groups;" page 387.) Until recently, there have been few studies that have sought to measure the energy cost of aerodynamic drag associated with the running events contested in track & field. Fewer still have explored the possibility of finding ways and means to reduce the same. (Len Brownlie, et al., Ann. Physiol. Anthrop., 1987, Vol. 6, No. 3, "The Influence of Apparel on Aerodynamic Drag in Running," page 133: "In contrast, (with skiing and cycling) systematic measures to reduce wind resistance in running have yet to be developed.") Nevertheless, at speeds associated with the 100 and 200 meter sprint events (10 meters / second, or $10m/s^{-1}$), and middle-distance events $(6m/s^{-1})$, aerodynamic drag is estimated to comprise 13.6 % and 7.5 %, respectively, of the total energy expenditure. (L.G.C.E. Pugh, J. Physiol., 1971, Vol. 213, "The Influence Of Wind Resistance In Running And Walking And The Mechanical Efficiency of Work Against Horizontal Or Vertical Forces;" page 255.) At a velocity of $10m\text{-}s^{-1}$

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a time savings of .25-.5 seconds would be possible over the distance
of 100 meters in the absence of aerodynamic drag. (C.T.M. Davies,
J. Appl. Physiol., 1980, Vol. 48, "Effects Of Wind Assistance And
Resistance On The Forward Motion Of A Runner," pages 702-709.)
S.F. Hoerner found that an aerodynamic drag reduction of 5-10%
could be attained when testing a nude human torso, as opposed to
one fitted with traditional athletic clothing. (S.F. Hoerner,
Fluid-Dynamic Drag, 1965: Cited by Brownlie, et al., Ann. Physiol.
Anthrop., 1987; page 134.) Form-fitting hooded body suits have
recently been developed which provide a 7.4% reduction in aerodynamic
drag over nude values, but some 6% of this reduction is attributed
to the hood covering the ears and hair of the head. (Brownlie,
et al., Ann. Physiol. Anthrop., 1987; page 137.) Estimates of
possible time savings over distances ranging from 100 meters to
the Marathon event are shown in the table reproduced below:

SS = Traditional Apparel

K = Body Suit

Race Distance	Base Velocity (m/s^{-1})	Performance time in each apparel		Time difference	
		SS	K	(min:sec)	%
42.2km	4.7	2h29:37.66	2h28:03.16	1:34.50	-1.05
1500 m	7.1	3:31.27	3:27.90	3.37	-1.62
400 m	8.8	45.45	44.30	1.15	-2.53
100 m	9.7	10.309	10.025	.284	-2.75

(Brownlie, et al., Ann. Physiol. Anthrop., 1987; Table 3, page 141.)

Brownlie notes that even if only 40% of the .284 second time saving
over 100 meters is possible a 1.65% improvement of performance would
still result, and in a field trial of the "K" body suit at an average
velocity of 7.43 m/s^{-1} an actual improvement in performance levels
of 1.17% was observed. However, the construction and materials
presently employed in "body suits" substantially compromise
physiological demands for thermal cooling when used in the long
distance events, or otherwise for lengthy durations. Moreover,
to the best of the inventor's knowledge little else has been

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attempted at this point to reduce the aerodynamic drag associated
with the contest of events in <u>Athletics</u>. The possible time and
energy savings that could be achieved with a reduction of
aerodynamic drag could exceed the winning margins in the contest
of various events and it is therefore considered a subject worthy
of serious study and endeavor.

The formula for calculating the aerodynamic drag on an object
is expressed:

$$\underline{D = .5 \ (p) \ (Ap) \ (Cd) \ V^2}$$ Wherein;

D = The Force of Drag in Newtons (N),

p = Air Density (kgm^3),

Ap= Projected or Frontal Area Normal to the air stream (m^2),

Cd= The Coeffient of drag expressing the aerodynamic efficiency
of a particular object,

V = Velocity of the object in still air. (m/s^{-1})

A brief discussion of each component of the above formula will
aid the reader in following later discussion of the present
invention and the ways and means by which a substantial reduction
in aerodynamic drag can be achieved.

Air density (p) can have a substantial effect on the generation
of aerodynamic drag (D). A.J. Ward-Smith studied the Athletic
performances delivered at the 1968 Olympic Games held at 2,300
meters altitude in Mexico City. The density of the air at that
altitude is 23.5 % less than at sea level. In the course of
studying the results of the 100, 200, and 400 meter events it was
found that performances were 1.7 % faster than would normally
have been expected. The longest standing record in track & field
at the present time, Bob Beamon's long jump of 8.90 meters,
was established during the 1968 Olympic Games competition. (See
A.J. Ward-Smith, <u>Biomechanics</u>, 1984, Vol. 17, "Air Resistance
And Its Influence On The Biomechanics And Energies Of Sprinting
At Sea Level And At Altitude;" pages 339-347.) In sum, the
less dense the air the lower the aerodynamic drag and the faster
or farther can an individual run or jump.

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The projected or frontal area normal to the air stream or wind (Ap) has a dramatic effect on the production of aerodynamic drag. In the sports of bobsled, skiing, and bicycling it has been possible to substantially reduce the projected frontal area by changing body posture, e.g., the "tuck" position in downhill skiing and the like for bicycling.   Greg LeMond, the U.S. winner of the 1989 Tour de France used aerodynamically efficient head gear and handle-bars permitting a narrow grip and "tuck" position during the last 15 kilometer stage of the race to overcome a 50 second deficit and deliver the fastest all-time performance over that leg of the race. However, it is not possible to significantly change the posture of athletes competing in running events in track & field. During running the projected frontal area (Ap) varies by no more than 6%. (Len Brownlie, NIKE Sport Research Review, 1989, May-June, "High Performance Sports Apparel;" page 2.) Moreover, since the finish of races conducted in the running events is determined by measuring when the torso first crosses the nearer side of the finish line it would be inappropriate to alter the front side of the torso in an attempt to reduce projected frontal area. However, the inventor sees no reason why such could not be attempted with respect to the long jump and triple jump events. Again, it should be noted that 6% of the 7.4% reduction in aerodynamic drag achieved by using "body suits" can be attributed to the use of a hood to cover the ears and hair of the head. Projected frontal area (Ap) and its impact on the coefficient of drag (Cd) is then a much larger factor at the velocities under consideration, than aerodynamic drag induced by surface friction: (i.e., Less than or equal to 1.4% of the 7.4 % reduction achieved by the use of "body suits.") An individual's projected frontal area can be precisely determined by planimetry. However, a less exacting method to calculate the projected frontal area (Ap) is expressed by the formula:

$Ap = .597 (H)^{.725}(M)^{.425}$ wherein;

H = The individual's height in meters, and

M = The individual's mass in kilograms.

(Chester R. Kyle and Vincent J. Caiozzo, Medicine and Science in Sports and Exercise, 1986, Vol. 18, No. 5, "The Effect of Athletic Clothing Aerodynamics Upon Running Speed;" page 511.)

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"Drafting," or closely following behind a leading competitor proves an effective method for reducing the trailing athlete's projected frontal area (Ap) normal to the air stream or wind. It should be noted that competitors increase the aerodynamic drag experienced by both when they run side by side.   Pugh calculated that an 80% aerodynamic drag reduction could be achieved at a velocity of 6m/s^{-1} by following directly behind a leading competitor at a distance of 1 meter. (Pugh, J. Physiol., 1971; page 271.) By way of comparison, Brownlie calculated a 62.7% aerodynamic drag reduction at a velocity of 7.1m/s^{-1} and a separation of 1 meter. In the practical application, a separation of 1 meter is not easily attained, but something nearer 2 meters is clearly possible. (Brownlie, Ann. Physiol. Anthrop., 1987; page 141.) Kyle found that at a velocity corresponding to the middle distance events 6.13m/s^{-1} a 40% aerodynamic drag reduction was possible with a spacing of 2 meters, and calculated that at the velocity of the 1500 meter world record, 7m/s^{-1} an advantage of 1.66 seconds / 400 meter lap could be generated by drafting. (Kyle, Ergonomics, 1979; pages 395-396.) Pugh calculated, that given an aerodynamic drag energy cost of 7.5 % associated with running the middle distance events at a velocity of 6.0 m/s^{-1} that an 80% reduction in aerodynamic drag would yield an energy savings of 6% oxygen uptake, i.e., VO$_2$, which when applied towards improved performance would provide an increase in velocity from 6.0 to 6.4 m/s^{-1} thus a 3.5 second increase in pace from 66.0 to 62.5 seconds / 400 meter lap. (Pugh, J. Physiol., 1971; page 275.) If Pugh's calculations are adjusted in light of the drafting conditions that can be attained in the practical application the results appear as shown below:

VO$_2$ Energy Cost		% Percent Drag Reduction		% Percent VO$_2$ Savings		Pace Change Sec./400m	Gain Sec.
7.5	*	80%	=	6	%	66 to 62.5	3.5
7.5	*	40%	=	3	%	66 to 64.25	1.75
7.5	*	30%	=	2.25%		66 to 64.68	1.315
7.5	*	20%	=	1.5	%	66 to 65.125	.875

As something in the range of 1.0 second / 400 meters is the commonly observed or perceived benefit obtained by drafting a leading runner in the middle distance events, and in light of Pugh's data and the calculations above: It would appear that something between 20 % and 40% represents the aerodynamic drag reduction obtained when drafting a leading runner in the middle distance events.

The coefficient of drag (Cd) is a non-dimentional value which expresses the aerodynamic efficiency of an object. The higher the value happens to be the less aerodynamically efficient is the object. The coefficient of drag (Cd) for a sphere is approximately 1.3, and that of a cylinder 1.2.   The human torso closely resembles a cyclinder and its coefficient of drag is normally in the range of .9 to 1.1. A tear-drop shaped object could have a coefficient of drag in the range of .1 to .3. (Albert C. Gross, et al., Scientific American, 1983, Vol. 249, "The Aerodynamics of Human Powered Land Vehicles;" page 145.) The coefficient of drag (Cd) is derived by the formula:

Cd = D / (q) (Ap) wherein;

Ap = Projected frontal Area Normal to Air Stream (m^2),

q = Dynamic Pressure of the moving air stream, equal to the kinetic energy per unit volume of a moving solid body,

D = Aerodynamic drag force in Newtons (N),

V = Velocity of object and /or normal air stream or wind (m/s^{-1}),

q = .5 (p)(V)^2 wherein;

p = Air Density (kgm^3).

However, the coefficient of drag (Cd) is also a function of another dimensionless group, the Reynold's Number (R), as expressed by the equation:

R = (V)(1)/v wherein;

V = Velocity (m/s^{-1})

1 = A representative dimension of an object, e.g., diameter or length, or the projected frontal area (Ap),

v = kinematic viscosity of the air at a given temperature and pressure as given by the equation,

v = $\dfrac{\mu \text{ (air viscosity)}}{p \text{ (air density)}}$ i.e., the ratio of = v

(The formulas and equations above were derived from Pugh, J. Physiol., 1971, Vol. 213; page 257.)

The coefficient of drag (Cd) is normally a linear function of the Reynold's Number (R) at relatively low velocities and within the zone of laminar flow. However, as an object enters the transition zone, (i.e., as the object's velocity and / or that of the air stream becomes sufficient to generate turbulence that results in a slight narrowing of the object's wake), the coefficient of drag (Cd) remains relatively constant. Here, the aerodyanmic drag that would normally be induced by higher velocities is counteracted by the narrowing of the objects wake. Later, as velocity increases to the point where the critical Reynold's Number (Rcrit) is reached a condition of fully developed turbulence results which causes a more complete wake narrowing and a dramatic decrease in the object's coefficient of drag (Cd): (e.g., The coefficient of drag (Cd) of a cyclinder can decrease from 1.2 to a value of .3 when the critical Reynold's Number (Rcrit) is reached!) This phenomenon will be later addressed in greater detail and is represented in the graph shown below:
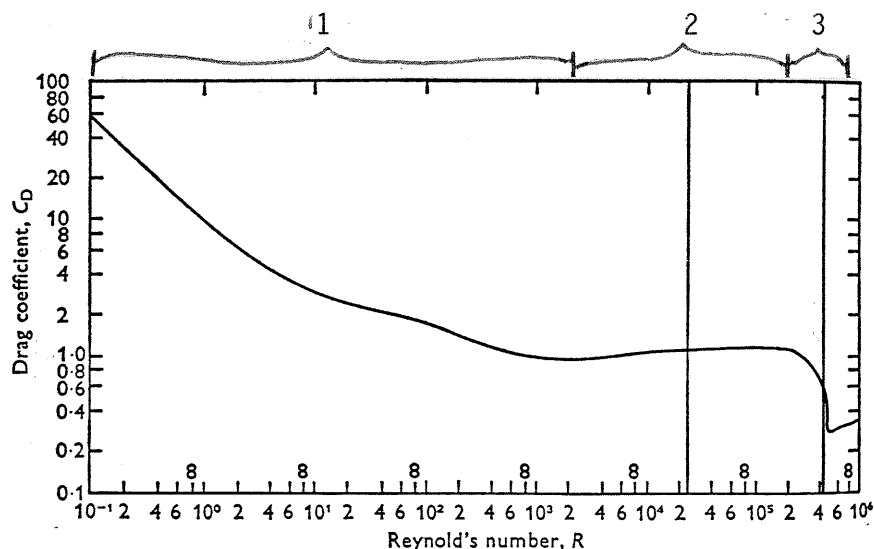

Fig. 1. The relation of the drag coefficient (C_D) and the Reynold's number (R) for a circular cylinder with its axis normal to the direction of air flow (redrawn from Schlichting, 1968). The vertical lines show limits of R over a range of wind velocities extending from 1·5 to 18·5 m/sec.

(The graph above can be found in Pugh, J. Physiol., 1971, Vol. 213; page 258.) The (1) zone of laminar flow, (2) the transition zone, and (3) the zone of fully developed turbulence is represented at the upper border of the figure, as indicated by the inventor.

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Again, this disclosure will return to more fully address the possible
implications of the effect of the critical Reynold's Number (Rcrit)
upon an object's coefficient of drag (Cd), as this relates
to enhancing human performance. — *See pages 21-22. See also bottom p. 12.*

The velocity of an object (V) and /or that of the air stream
has a "geometric" effect on the generation of aerodynamic drag.
Aerodynamic drag increases as the square of velocity. In short,
the faster the speeds involved in human performance, the more does
aerodynamic drag become a significant factor.   In running events,
as velocity increases so does the frequency and length of an athlete's
stride: Moreover, the "flight time," i.e., the periods when both
feet of a runner are off the ground also increases. (Kyle, Scientific
American, 1986, Vol. 254, "Athletic Clothing;" page 106.) "Since
the aerodynamic drag force is proportional to the square of the
relative velocity, head winds, tail winds and even cross winds can
drastically change both aerodynamic drag and the power requirement."
(Gross, et. al., Scientific American, 1983; page 151.) The energy
costs and possible savings associated with an individual's running
velocity will be addressed more comletely later in this treatment. — *See pages 19-20.*
However, it was observed that oxygen uptake (VO_2) increased as the
square of wind velocity, and power increased as a cube of velocity
during various experimental trials. (See Pugh, J. Physiol., 1971;
page 255, and Gross, et al., Scientific American, 1983; page 151.)
As previously addressed, the velocity of an object (V) and / or
that of the air stream is a major factor in determining the Reynold's
Number (R), and thereby, the coefficient of drag (Cd) when the
transition zone, or zone of fully developed turbulence are entered.
Having briefly addressed the relevance of variables associated
with the formula expressing the derivation of aerodynamic drag
force this treament will turn to a disclosure concerning just what
occurs as an object moves through, and / or an air stream moves
in a direction normal to the object.

        Aerodynamic drag force is generated by two sources, friction
induced drag and pressure induced drag. The high sheen of the
materials presently being employed in "body suits" is intented
to minimize friction drag. However, as noted earlier on page 4
of this disclosure friction drag is a relatively small factor at
the velocities under consideration: Of the 7.4% aerodynamic drag
reduction attained by use of the "body suits" over nude values,
6% was attributed to the hood covering the ears and hair of the
head leaving approximately 1.4% to be accounted for by a reduction
in friction drag. As will be addressed below, the use of material
having a high sheen about the sides of an object would prove
counterproductive to the reduction of pressure drag. The reduction
of pressure induced aerodynamic drag then becomes the primary task
for those interested in reducing aerodynamic drag force experienced
by the competitive athlete and thereby facilitating improvements
in the level of human performance.

        It will be helpful to illustrate and describe just what takes
place as an object moves through an air stream, or is otherwise
enveloped by the same. The pattern of the air stream about an
object is commonly referred to as the laminar flow and represented
by roughly parallel lines enveloping the object's cross-section
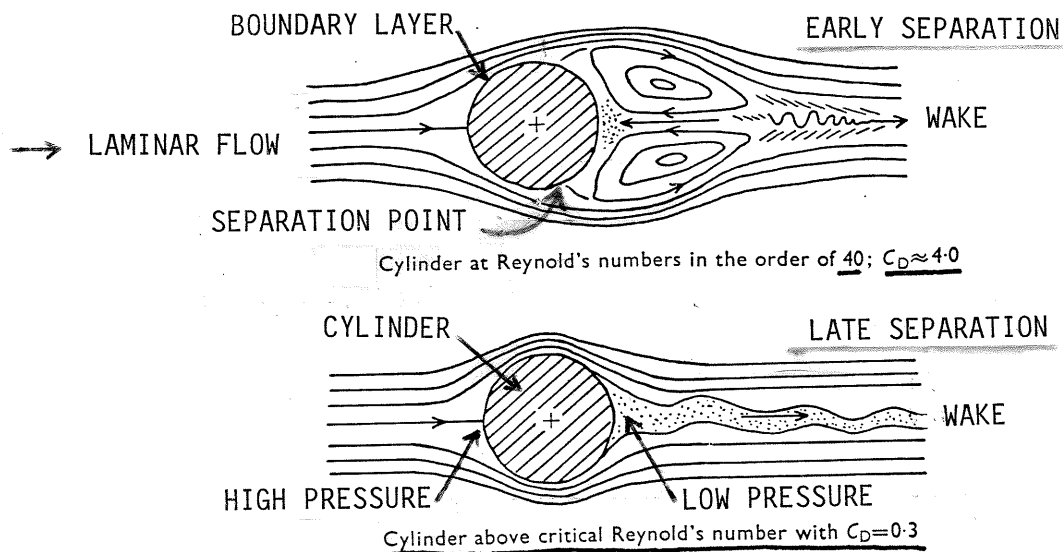as seen of the cylinder shown below:
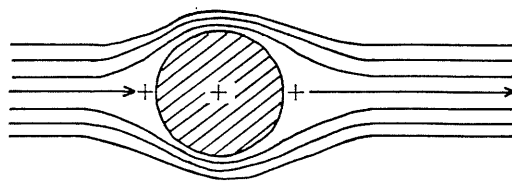
(1) Flow pattern of circular cylinder in non-viscous flow; no drag

In this particular representation, non-viscious air flow prevents
the generation of aerodynamic drag. Pressure is evenly distributed
about the cyclinder. However, non-viscous air flow is not encountered
when performing in a natural environment. (This figure can be found
in Pugh, J. Physiol., 1971, Vol. 213; page 259.)

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In the figure below that part of the air stream bordering
and in contact with the surface of the object, or cylinder is
referred to as the boundary layer. At the point of lowest pressure
the boundary layer of the laminar flow will separate from the surface
of the object, or cylinder.   This is called the separation point.
The separation of the boundary layer of laminar flow results in
the generation of a wake characterized by low pressure behind a
moving object, or cylinder. Normally, the earlier the separation
point the wider and larger is the wake generated. This has been
represented in the two figures shown below:

BOUNDARY LAYER   EARLY SEPARATION

LAMINAR FLOW   WAKE

SEPARATION POINT

Cylinder at Reynold's numbers in the order of 40; $C_D \approx 4 \cdot 0$

CYLINDER   LATE SEPARATION

WAKE

HIGH PRESSURE   LOW PRESSURE

Cylinder above critical Reynold's number with $C_D = 0 \cdot 3$

(The figures aboves were derived from Pugh, J. Physiol., 1971,
Vol. 213; page 259.)

It is the imbalance and build-up or presence of high pressure
on one side of an object relative to the low pressure on the other
side that is experienced as aerodynamic drag force. The more
completely and evenly the pressure is distributed around an object
the less pressure induced aerodynamic drag is generated. In order
to reduce high pressure build-up on the "front" side of an object
and thereby minimize the generation of pressure induce aerodynamic
drag the boundary layer characterized by high pressure must "stick"
to the object and follow as far as possible around its sides to the
rear of the object, thus delaying as much as possible separation

of the boundary layer. As addressed earlier at the top of page 9
of this disclosure: The use of high sheen materials to reduce
friction induced aerodynamic drag is effective on the frontal
areas of an object, but inappropriate for use about the sides of
an object, e.g., the human torso. High sheen materials used in
this area can facilitate early boundary layer separation and
thereby increase the production of pressure induced aerodynamic
drag which is far and way the largest component of aerodynamic
drag force experienced at the velocities under consideration.
In this connection a surface roughness effect has been observed.
A suitable structure, texture, material and the like employed
about the sides of an object, e.g., the human torso, can cause
the boundary layer to become prematurely turbulent and thereby
delay boundary layer separation. The generated turbulence has
the effect of causing the high pressure to "stick" to the object
longer and flow further around its sides, thus reducing the size
of the wake and low pressure area at the rear of the object.
This results in a reduction of pressure induced aerodyanmic
drag, and it is the reason, e.g., why golf balls have those
interesting dimples! Hoerner (1965) found that nude subjects
demonstrated an aerodynamic drag reduction of 5-10 % over those
wearing traditional apparel. However, the use of a material of
select roughness, e.g., a fine woven wool, can reduce aerodynamic
drag .5-.6% over nude values. (Chester R. Kyle and Vincent J.
Caiozzo, Medicine and Science in Sport and Exercise, 1986, Vol. 18,
No. 5, "The Effect Of Athletic Clothing Aerodynamics Upon Running
Speed;" page 510.) Moreover, surface roughness can influence
the advent of transition and fully developed turbulence and lower
the velocity at which these events take place as expressed in
the passage from Kyle and Caiozzo (1986) below:

> Hoerner shows that the drag on a cylinder is radically
> effected by surface roughness. Roughness of the right
> scale causes the boundary layer to turn turbulent
> prematurely, and lowers the drag caused by pressure
> differences on the leading and trailing faces of the
> cylinder.

                    *   *   *   *   *

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> Normally, the transition on a smooth cylinder would
> be at a Reynold's number of 5×10^5, however, with
> proper surface roughness, Hoerner shows that transition
> can occur at Reynold's numbers as low as 4×10^4.

<div align="center">*   *   *   *   *   *</div>

> Proper clothing roughness at critical locations could
> lower the air drag of a competitor and give an advantage
> over opponents with normal clothing.

It should be noted that the human torso is thought to undergo

transition to a condition of fully developed turbulence at a

velocity of /18m/s,$^{-1}$ *approximately* thus well above the velocity of 10-12m/s^{-1}

attained during the 100 and 200 meter events. However, as can

be seen from the figure on page 7 above of this disclosure: Surface

roughness, and / or other measures than would lower the transition

point from a Reynold's number of 5×10^5 to 4×10^4 could permit

the generation of fully developed turbulence within the range

of velocities attained during the contest of running events. To

the best of the inventor's knowledge, no one has constructed a

body suit utilizing proper clothing roughness at critical locations

with the intention of lowering the aerodynamic drag of an individual

relative to opponents equipped with traditional clothing.

At this point, it will be possible to conclude discussion of

the influence of the critical Reynold's number (Rcrit) on the

coefficient of drag (Cd) briefly address on page 7 of the present

disclosure above. Again, when a cylinder reaches a certain velocity

relative to the air stream the critical Reynold's number is reached

and fully developed turbulence results.   When a cylinder undergoes

fully developed turbulence its coefficient of drag can drop from

a value of 1.2 to .3: This phenomenon has been described by Pugh

(1971) as reproduced below:

> It is seen that Cd is fairly constant over a range of R
> values extending from 10^3 to 10^5, and that the values of
> R within the range of air velocities employed in this
> investigation occupied the upper end of this range. Above
> $R = 1 \times 10^5$, Cd falls progressively, reaching a new low level
> at about $R = 5 \times 10^5$, which is known as the critical Reynold's
> number (Rcrit). The fall in Cd as Rcrit is approached is
> associated with a change in the characteristics of the

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air flow behind the body. This change consists in the break-up of the wake from a more or less orderly system of vortices (Fig. 2) to a completely disordered state of random turbulence. In the presence of this degree of turbulence the boundary layer of air clinging to the sides of the body extends further round the circumference causing the wake to narrow, thereby reducing drag. This condition is known as fully developed turbulence.
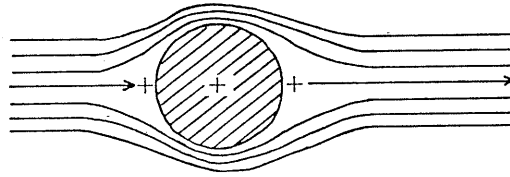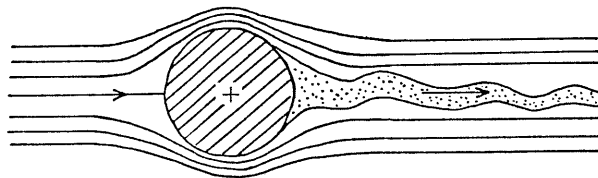
(1) Flow pattern of circular cylinder in non-viscous flow; no drag
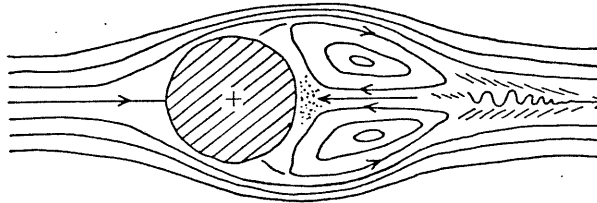
(2) Cylinder at Reynold's numbers in the order of 40; $C_D \approx 4 \cdot 0$
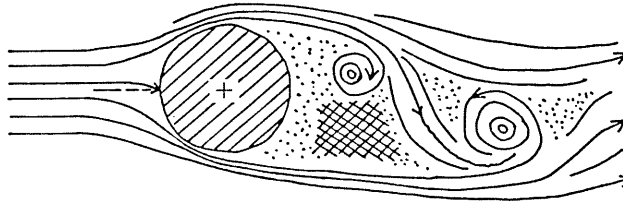
(3) Cylinder between $R_d = 10^4$ and 10^5; vortex street with $C_D = 1 \cdot 2$

(4) Cylinder above critical Reynold's number with $C_D = 0 \cdot 3$

Fig. 2. Diagrammatic representation of the air flow patterns round a circular cylinder at various Reynold's number. Note the reduction of drag (C_D) above the critical Reynold's number (redrawn from Hoerner, S. F., 1965).

(The block quotation above was reproduced from Pugh, J. Physiol., 1971, Vol. 213; page 257, and the figures page 259.)

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The above discussion concerning the critical Reynold's number
and an object's coefficient of drag has treated the shape of a
cylinder, and the human torso as a "given." With a cylinder-
shaped object roughly 70-90 % of the drag stems from the front,
or leading surface, and 10-30% from the rear, or trailing side
of the object, e.g., when speaking of a human torso. (Private
conversation with Chester R. Kyle, 1989.) The influence of altering
the shape of a cylinder upon its coefficient of drag was explored
by Hoerner (1965). Figure 8 from page 3-7 of Hoerner's privately
published book entitled: Fluid Dynamic Drag has been reproduced
as shown below:

a) $C_D. = 0.94$ (1.11)   A R C (19,b)

THWAITES FLAP

b) $C_D = 0.59$ (1.03)   CALTECH (12)

c) $C_D. = 0.62$ (1.03)   CALTECH (12)

d) $C_D. = 0.89$ (1.19)   D V L (1934)

e) $C_D. = 1.4$ (1.7)   CALTECH (12)

V

f) $C_D. = 1.6$ (1.9)   HOERNER (1936)
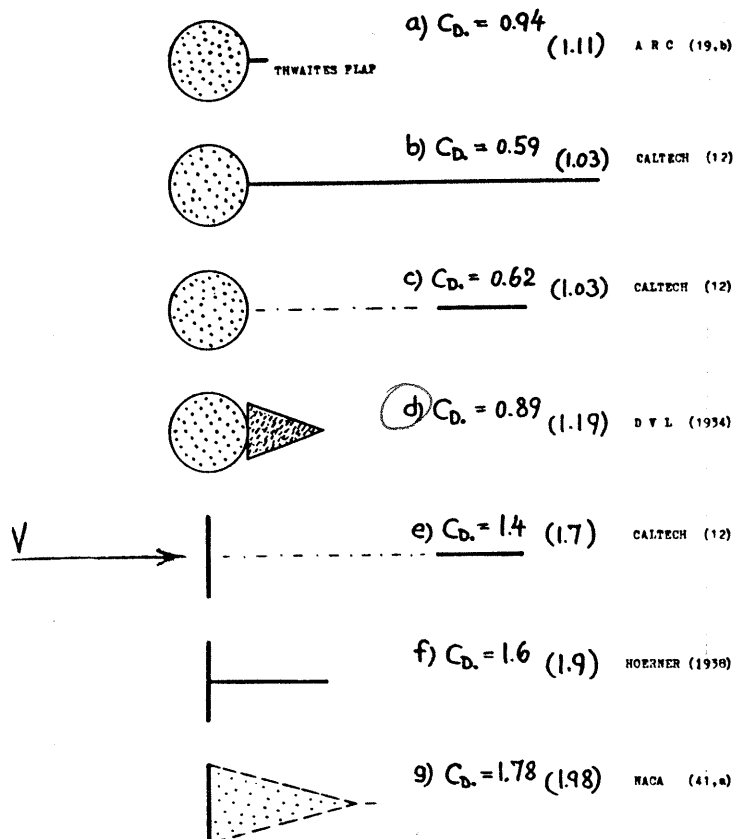
g) $C_D. = 1.78$ (1.98)   NACA (41,a)

Figure 8. Influence of "splitter" plates (and similar devices)
on the drag coefficient of vortex-street-producing shapes
(tested between walls). The values in brackets are the drag
coefficients without wake interference. The Reynolds numbers
(on d or g) are between 10^4 and 10^5.

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The inventor wishes to draw attention to object (d) in Figure 8. shown above. By streamlining the rear, or trailing surface of the cylinder creating a "V-shape" the object's coefficient of drag was reduced from 1.19 to .89. That is a reduction of .3, or approximately 22%. The coefficient of drag for a human torso is normally in the range of .9 to 1.1. If a similar reduction of 22% could be achieved the coefficient of drag would drop .198 to .242, and thus be in the range of .702 to .858. The coefficient of drag obtained by such a configuration would no longer follow the function shown on page 7 of the present disclosure above. According to Hoerner:

> With respect to the arrangements "d" and "g" in figure 8, (shown on page 14 of the present disclosure above), we suggest that the reduction of the drag coefficient is not a matter of "streamlining." The wedges attached to the rear of the cylinder and plate, respectively, simply reduce the motion of the vortex street. (Hoerner, Fluid-Dynamic Drag, 1965; page 3-7.)

The question then becomes how to determine the practical impact of a 22% reduction in the coefficient of drag (Cd) upon human performance. The inventor contacted Chester R. Kyle on 29-30th August and it was he who calculated the estimated time and distance savings over 100 meters associated with a reduction in the coefficient of drag (Cd) of this magnitude. The equations and data used to perform these calculations will be provided directly. In 1927, A.V. Hill conducted a study of sprinters and derived a simple, but exceptionally accurate equation that predicted the time-velocity-distance relation:

$$MdV/dt = T - a_1V \quad \text{wherein;}$$

t = Time in seconds,

T = Thrust in Newtons (N),

a_1 = An arbitrary constant related to viscous muscle friction with units Nms^{-1}.

Kyle reproduced this equation and modified it to allow for wind resistance as seen below. (Kyle, Medicine and Science in Sports And Exercise, 1986; page 512.)

$$MdV/dt = T - a_1V - a_2V^2 \text{ wherein;}$$

$$a_2 = (p)(Cd)(Ap)/2, \text{ and letting,}$$

$$q = 4Ta_2 + a_1^2 \text{ and } F = a_1V + a_2V^2 \text{ with}$$

$$X = \text{Distance in meters and Velocity (V) and } X = 0 \text{ at } t = 0,$$

The solution to the equation $MdV/dt = T - a_1V - a_2V^2$ is then:

$$t = (M/\sqrt{q}) \ln \frac{(2a_2V/(a_1 + \sqrt{q})) + 1}{(2a_2V/(a_1 - \sqrt{q})) + 1}$$

$$X = (M/2a_2) \ln (T/T-F)) - (a_1/2a_2)t$$

t = Time in seconds, and

X = Distance in meters.

The values that Kyle used to calculate the impact of a 22% reduction in the coefficient of drag (Cd) were those of Mel Lattany, as recorded by Kyle and used in the original study. (Kyle, Medicine and Science in Sports And Exercise, 1986, page 512.)   The Lattany data is provided below:

$$T = 678.3$$
$$a_1 = 62.39$$
$$m = 70.8$$
$$p = 1.1774$$

Kyle found that the model predicted Lattany's times with accuracy and with a coefficient of drag (Cd) of 1.0 his predicted performance over 100 meters was 10.747 seconds. Calculating a reduction in the coefficient of drag of 22% from 1.0 to .78 by configuring the rear of the torso in a manner consistent with figure "d" as shown on page 14 of the present disclosure above provides a predicted performance of 10.659 over 100 meters. This constitutes a time savings of .088 seconds and an advantage of .917 meters. Note that Lattany's performance and velocity is below that of world class performance at 100 meters which is commonly contested at slightly less than 10.0 seconds. Since aerodynamic drag is a function of the square of velocity the above estimate with respect to time savings and advantage in meters is conservative if and when applied to world class performances.

The time savings calculated by Kyle of .088 seconds with respect
to a 100 meter performance of 10.747, thus bringing the predicted
time down to 10.659 represents a .824 % improvement in perfomance.
If we apply .8 % improvement to the present world records in events
ranging from 100 meters to the Marathon the following results are
obtained:

EVENT	PRESENT WR	PREDICTED WR	TIME SAVINGS
100 M	9.83	9.75	- .078
400 M	43.29	42.94	- .346
800 M	1:41.73	1:40.91	- .813
1500 M	3:29.46	3:27.78	- 1.675
5000 M	12:58.39	12:52.16	- 6.227
10000 M	27:08.00	26:55.00	- 13.000
MARATHON	2h 06:50.00	2h 05:49.00	- 60.880

(handwritten margin note: Note: A bit conservative re: shorter distances and would over-estimate savings at longer distances since v velocity drops from 10-12 mps to ~ 6 mps.)

Moreover, Kyle pointed out that the change in performance
obtained through a 22% reduction in the coefficient of drag (Cd)
was consisted with that obtained through a 23% reduction in air
density (p) at 2,300 meters altitude with respect to the 1968
Olympic Games held in Mexico City.   Again, the equation for
determining aerodynamic drag is shown below:

$$D = .5 \ (p)(Cd)(Ap)(V^2)$$

A 23% decrease in the value for air density (p) should have
nearly the same impact on the generation of aerodynamic drag,
as a 22% decrease in the value for the coefficient of drag (Cd)
in the equation shown above. In 1986, Kyle determined while (using
the same data on Mel Lattany employed in the above calculations),
that with roughly 20% less wind resistance due to the decrease
in the value of air density (p) that Lattany's performance would
be .08 seconds less at 100 meters and .16 seconds less at 200
meters than at sea level. (Kyle, Medicine and Science in Sport
And Exercise, 1986; page 513.) In a private conversation with

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the inventor on August 30, 1989 Kyle drew attention to this
correlation as supporting the thrust of the predicted time savings
and advantage in distance that could be attained by reducing the
coefficient of drag (Cd) as discussed above. Moreover, Kyle stressed
that the model provided conservative estimates as compared to actual
time savings.   This was noted in his article published in 1986
as reproduced below:

> At Mexico City, the elevation is 2,260 m, and the air
> density is about 20% lower than at sea level. The wind
> resistance therefore would be about 20% less. With 20%
> less wind resistance, equations 5 and 6 predict the time
> for Mel Lattany to be .08 s less at 100 m and 0.16 s less
> at 200 m than at sea level. This is a conservative
> estimate compared to actual competition time savings,
> which Ward-Smith (f.n.22) has shown to be approximately
> double those predicted. In the present calculation, the
> maximal speed increased about 1% as to compared to actual
> increases of about 1.7% in competition. (f.n.22). Thus,
> if anything, the sprinting models used seem to under-
> estimate the benefit of aerodynamic drag reduction.

If in fact the actual competitive time savings are double those
predicted by the model the projected .8% improvement becomes a
1.6% improvement in actual performance levels. Doubling the
time savings indicated in the table shown on page 17 of the present
disclosure yields the following results:

EVENT	PRESENT WR	PREDICTED WR	TIME SAVINGS
100 M	9.83	9.67	- .156
400 M	43.29	42.59	- .692
800 M	1:41.73	1:40.10	- 1.626
1500 M	3:29.46	3:26.11	- 3.350
5000 M	12:58.39	12:45.93	- 12.454
10000 M	27:08.00	26:42.00	- 26.000
MARATHON	2h 06:50.00	2h 04:48.24	- 2:01.760

Probably the largest saving estimate that could be seriously entertained.

The results shown on page 17 of this disclosure corresponding to
a .8% improvement in performance levels would exceed the winning
margin in most world class competitions. However, the results
shown above corresponding to a 1.6% improvement in performance
levels would re-write the existing world records by a large margin.

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EQUATIONS USED FOR ESTIMATING ENERGY EXPENDITURE, POWER AND WORK
IN THE PRESENCE OF AIR STREAM RESISTANCE

(Reproduced from Pugh, J. Physiol., 1971, Vol. 213; pages 258-261.)

Work done against wind resistance. The external work rate $\dot{w}$ of a
man walking on a treadmill at a speed $\dot{s}$ against a wind of velocity v,
which exerts on his body a force P is given by

$\dot{w} = P\dot{s}$ and since
$P \propto v^2$
$\dot{w} \propto \dot{s}v^2$.

Rate of energy expenditure (power developed). The rate of energy
expenditure (E), or power developed, in performing work against wind
at a rate $\dot{w}$ is given by the expression

E = $\dot{w}$/ke,

where e is the mechanical efficiency and k is a constant
converting the terms to thermal units. Hence

E = $P\dot{s}$/ ke.

For exercise in the steady state E can be expressed in terms of the
concurrent oxygen intake in ml./sec: and with $P\dot{s}$ in Kg m/sec, k is
equal to

.0049 / .00235 = 1 / 2.09,

where .0049 is the thermal equivalent of oxygen in kcal/ml. at r = .9,
and .00235 is the thermal equivalent of mechanical work in kcal/kgm.

Writing $\triangle VO_2$ for the extra O_2 intake due to the presence of wind, i.e.
observed VO_2 at the same treadmill speed ($\dot{s}$) without wind we get

$\triangle VO_2 = \dot{w}$/2.09e, or
$\triangle VO_2 = P\dot{s}$/2.09e.   Hence
e = $P\dot{s}$/2.09 $\triangle VO_2$.

* * * * * * * * * * * * *

(Reproduced from Kyle, Medicine and Science in Sport and Exercise,
1986, Vol. 18, No. 5; pages 513-514.)

8) E = .1292 + 4.142(V) + .00571 * n * V^3 wherein;
    E = Metabolic energy consumption in wkg^{-1} , and
        n is a shielding factor.

    Other formulas for estimating mechanical power in running,
    including wind resistance:

9) Em = 1.437 (V) - .00394 (k)V^3 and
10) Em = 2.037 (V) - .00394 (k)V^3.

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Table showing calculations of the effect of a 2% reduction in
aerodynamic drag on performances from Kyle, Medicine and Science
in Sports and Exercise, 1986, Vol. 18, No. 5; page 514.

TABLE 6. Advantage due to a 2% reduction in aerodynamic drag.

Distance (m)	Average Speed (ms^{-1})	Time Savings [s (I)]	Advantage (m)		
			I	II	III
100	10.07	0.01	0.1	—	—
200	10.15	0.02	0.2	—	—
400	9.12	0.08	0.7	1.9	1.2
800	7.86	0.14	1.1	2.7	1.8
1500	7.12	0.24	1.7	4.2	2.7
5000	6.41	0.76	4.9	11.3	7.3
10000	6.09	1.46	8.9	20.5	13.2
Marathon	5.50	5.70	31.3	70.2	45.4

I = from equations 5, 6, and 8; II = from equation 9; and III = from equation 10.

RE: EFFECT OF REYNOLD'S NUMBER CHANGE ON Cd:

According to Brownlie, "the effects of Reynold's number on Cd are constant at velocities below $18.5m/s^{-1}$ (Pugh, 1976; Davies, 1980)." (Brownlie, et al., Ann. Physiol. Anthrop., 1987, Vol. 6, No. 3; page 135.) And Brownlie later states: "The relatively narrow range of Cd (.96 to .98) observed here for the SS apparel suggests that the range of velocities selected were below the threshold required to generate a critical Reynold's number which would have caused a sharp decline in Cd." (Brownlie, et. al., Ann. Physiol. Anthrop., 1987, Vol. 6, No. 3; page 140.) However, Pugh suggested the following:

> There are many factors affecting Rcrit such as roughness or irregulatities of surface, variations in limb and trunk dimensions, wind turbulence etc., and it is impossible at present to estimate Rcrit for man, particularly for man during movement. . . . Accordingly the question whether running speed influences the drag coefficient must be left open. (Pugh, J. Physiol., 1971, Vol. 213; pages 272-273.)

The inventor suggests that the question of whether Rcrit can be lowered by the use of select materials, design, and modification of the rear of the torso as seen in figure "d" on page 14 of the present disclosure is open, especially as the coefficient of drag obtained by such a configuration would no longer follow the function shown on page 7 of the present disclosure. Moreover, athletes competing in the 100 and 200 meter events sometimes face a headwind normal to the direction of the sprint and their forward velocity.   There is the possibility that with a terminal velocity in the 100 meter event of somewhere around $12m/s^{-1}$ and a headwind normal to the athlete exceeding $6m/s^{-1}$ that the resultant, or relative velocity of the air stream in excess of $18m/s^{-1}$, and thereby, the critical Reynold's number (Rcrit) could induce fully developed turbulence and a dramatic drop in the coefficient of drag from .9 to 1.1 to somewhere under .7. In fact, it might be possible to coordinate the generation of an air stream at a desired velocity and have it meet the athletes at a predetermined time and distance during the conduct of the 100 meter event, e.g., at the 40 meter point with the intention of inducing fully developed turbulence

and thereby a dramatic reduction in the coefficient of drag (Cd)
that would facilitate faster performances. Wind generators have
been used in film-making for some time and could be employed,
e.g., by European meet promoters to optimize conditions for record
attempts.   The odd thing being that instead of using the wind
as an aid by putting it to the rear of the contestants, athletes
would be running into a headwind of a specific velocity in order
to trigger a dramatic decrease in their coefficient of drag. It
is an open question at this point as to whether, or to what degree
this technique would be effective. It should also be noted that
the range of resultant, or relative velocity necessary for optimal
aerodyanmic drag reduction using this technique would be narrow,
as shown, e.g., in the range of zone (3) in the figure shown on
page 7 of the present disclosure.

The inventor was referred to Len Brownlie at Simon Fraser University, British Columbia, Canada during the course of a private conversation with Chester R. Kyle in the summer of 1989.   The inventor then wrote Brownlie regarding his desire to test an article of apparel with the wedge or "V-shaped" back. It was then learned that Brownlie had been testing various fabrics on small cylinders for their aerodynamic properties.   The inventor suggested that silk of various types and grades be included in these tests. Furthermore, the inventor pointed out that by virtue of uncommon common sense "silks" had been used for several hundred years in connection with horse racing. Moreover, the inventor suggested the possibility of "constructive flutter" in this connection, i.e., that a certain degree of random fluttering of material about the sides or contours of an article of apparel could have a constructive effect in reducing aerodynamic drag. Somewhat loosely fitting "silks" or other fabrics could trigger or otherwise help to prematurely generate a condition of fully developed turbulence and wake narrowing, thus result in a dramatic aerodynamic drag reduction. This suggestion would tend to fly in the face of present efforts to utilize tight-fitting articles of clothing. In a private conversation on August 30, 1989 Brownlie revealed that an unexpected phenomenon was being observed in the testing of various fabrics. Without a surface roughness effect being present and in contrast with the same several high sheen materials appeared to affect the boundary layer in a manner as to delay separation of the laminar flow. Possible explanations would include a ducting effect as the air stream would penetrate the boundary of the fabric. However, vibration and "sound waves have an effect upon critical Reynold's number and resistance of round bodies." (Hoerner, <u>Fluid -Dynamic Drag</u>, 1965; page 3-8.) Again, the inventor suggests the possibility of vibration, or "constructive flutter" as contributory to a reduction in aerodynamic drag.
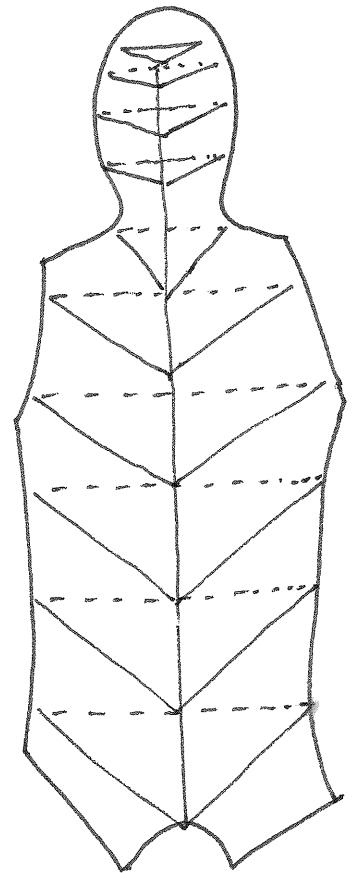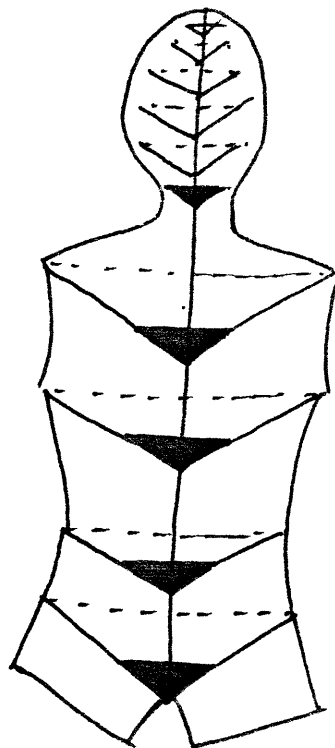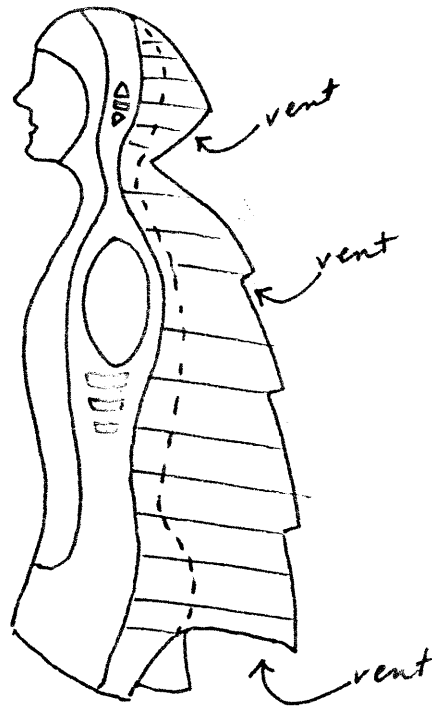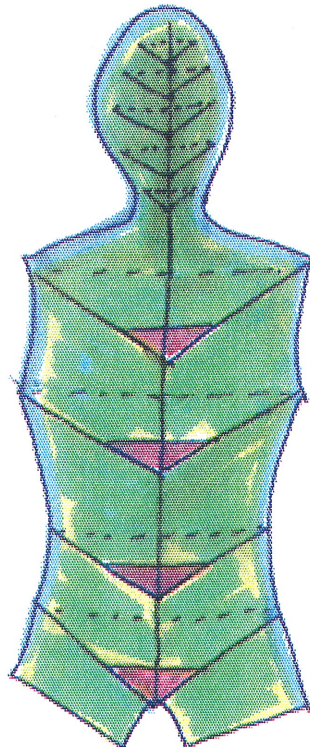
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SIDE

FRONT

BACK

TOP

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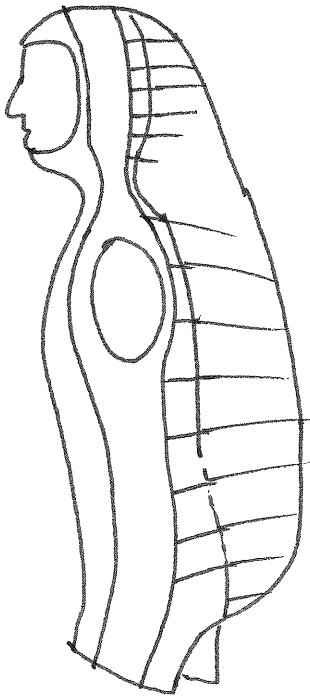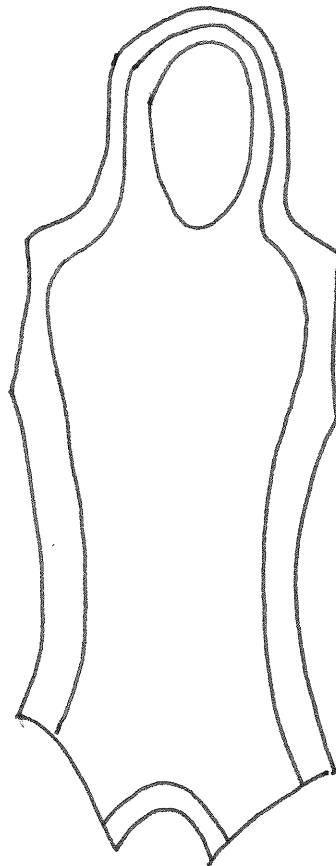
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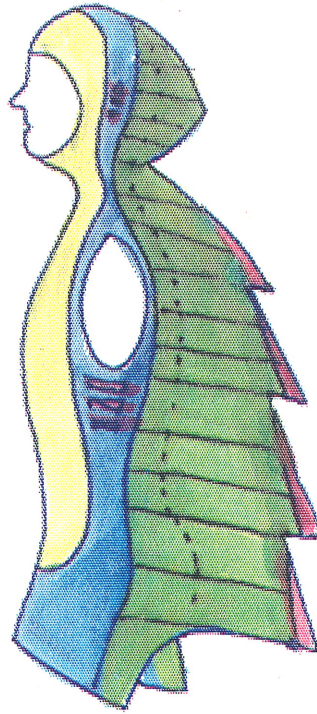
(26)

The suit would be vented and use light-weight foam re: structure so it wouldn't weigh anything or otherwise be cumbersome!

R. Lyden

What if Carl Lewis "Invaded" Japan as

⬇

Godzilla!

Would people go Wild!?

Enter The Dragon™

It Takes the Drag Off Your Back
And Leaves The DRAGON Theirs...